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Indian Standard

SEDIMENTATION IN RESERVOIRS — METHOD OF MEASUREMENT

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BUREAU OF INDIAN STANDARDS
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NEW DELHI 110002

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Reservoirs Sectional Committee, RVD 4

FOREWORD

This Indian Standard was adopted by the Bureau of Indian Standards, after the draft finalized by the Reservoirs Sectional Committee had been approved by the River Valley Division Council.

Silting of reservoirs play a vital role in the planning and design of storage reservoirs. The problem of sedimentation starts with the impounding of water in the reservoirs. Various factors influence the pattern of sediment deposition. The most predominant among them are rainfall characteristics like intensity, duration and annual volume and catchment characteristics like soil, geology of the area, vegetative cover, land use pattern and the reservoir operation.

To evaluate the effect of each of these and to serve as a guide for future planning, systematic capacity surveys of reservoirs should be undertaken at regular intervals. It also helps in planning corrective measures by way of catchment treatment, if surveys reveal abnormal deviations.

Depletion of storage in a reservoir on account of deposition of stream borne sediment poses many problems. Besides storage loss which is of much economic significance, there are planning and operational problems which require correct estimation of sediment deposit, its quantity and distribution in the entire body of the reservoir. The principal objectives of measurement of sedimentation in a reservoir are: (i) updating capacity chart for effective operation, (ii) collection of data for realistic project planning with respect to storage allocation, (iii) location of suitable areas for sediment extraction, outfall locations, economic implications and service expectancy, and identification of priority areas within the catchment from soil conservation point of view.

On account of the dynamic nature of water use planning, a periodic review of the storage status is essential from the point of view of optimum utilization, guaranteed performance and any alternatives in the system characteristics.

Indian Standard

SEDIMENTATION IN RESERVOIRS — METHOD OF MEASUREMENT

1 SCOPE

This standard lays down guidelines for methods of measurement of sedimentation in reservoir projects in order to assess the volume of deposit and the distribution which will be considered for making suitable allowance in the design of future projects at the time of their planning.

2 METHODS FOR MEASUREMENT OF SEDIMENTATION

There are broadly two methods for measurement of sedimentation in reservoirs :

a) Stream flow analysis, and
b) Capacity survey.

2.1 Stream Flow Analysis

2.1.1 Stream flow analysis is a continuous observation process consisting of measurement of inflows and outflows with sediment sampling. Apart from the measurements, accuracy of analysis depends a great deal on the proper estimation of unit mass of the deposited material from the point of view of volumetric conversion.

2.1.2 In this method, the sediment inflow into the reservoir including estimated bed load and the outflow therefrom are measured at all significant points of entry and exit. The difference gives the quantity of deposit during the period of analysis. The points of measurement should be sufficiently close to the reservoir periphery and particular care must be taken to complete outflow sampling before it meets the erodible channel downstream.

The analysis consists of two main parts: (1) measurement of water inflows and outflows, and (2) simultaneous measurement of sediment concentration.

This method gives quantity of deposit in gravimetric terms and conversion into volumetric units calls for the estimation of the average unit mass of the deposited sediment material. A direct method of doing this is by collecting systematic samples of the deposit in an undisturbed state from all over the reservoir bed and finding out a correlation between the average dry unit mass and the fractional composition of different grains such as clay, silt and sand.

2.2 Capacity Survey

2.2.1 Capacity survey is a direct measurement carried out periodically to assess the volume of deposit along with its location in the reservoirs. This method, however, indicates the total sediment yield of the entire catchment and not its subcatchmentwise origin. In case sub-catchmentwise sediment yield is required, sediment sampling of the different stream is necessary. The main survey methods are the contour method and the range line method.

2.2.2 In contour method, a contour map of the reservoir with suitable scale and contour interval is prepared, from which the capacity of the reservoir at the time of survey is computed. The difference in capacity between two surveys indicates the loss of capacity due to sediment deposition during the intervening period. In the case of reservoirs with large surface area, loss in storage capacity above maximum drawdown level may also be estimated by aerial surveys and remote sensing techniques.

In range method, survey is conducted along selected ranges across the reservoirs and this forms the basis for the computation of cubic contents between ranges.

2.2.3 While contour method of survey is generally applicable for all types of reservoir shapes, use of range method should be limited to relatively straight reaches. A suitable combination may also be justified in some cases.

2.3 Survey Equipment for Capacity Survey

2.3.1 The basis items of survey are : (i) Horizontal or distance measurement, (ii) Vertical or depth measurement. Some of the principal equipment and instruments required for the hydrographic and topographic coverage in relation to the above measurements include the following.

2.3.1.1 *Distance measuring equipment*

Survey equipment like chain, tape, plane table, transit sextant, range finder, electronic distance meter, etc and special hydrographic instruments like echo sounder, distance wheel, and other electronic equipment are generally used.

2.3.1.2 *Depth measuring equipment*

Conventional equipments like dumpy level, sounding poles, etc and special hydrographic equipment like echo-sounder, etc.

2.3.1.3 Movement facilities such as truck with trailer, motor launch, small boats.

2.3.1.4 Signalling and shore contact equipment such as Walkie-Talkie, radio telephone, day light signalling, lamp, etc.

2.3.1.5 Accessories such as ranging rods, range monuments and bench mark pillars etc, floating buoys, life buoys, tents etc.

2.3.1.6 A sediment depth measuring equipment called "Spud" is sometimes used in reconnaissance type work for a quick estimation of sediment depth. This device is also used in roughly tracing out the original profiles of the reservoir bottom in case it is not already available.

2.4 Contour Survey Method

2.4.1 The basic objective of this method is to prepare a contour map of the reservoir bed. There are quite a few field techniques available, the application of which depends mostly on the physical features of the reservoir, the operation schedule, working conditions and availability of instruments and other facilities. The most general method of contour survey are:

a) grid contour,
b) radial contouring,
c) circular contouring,
d) water surface mapping, and
e) air survey.

2.4.2 In this method, computation of capacity of reservoir is based on spot levels taken at grid points over the entire reservoir bed. Generally, a contour map of the reservoir with suitable scale and contour interval is prepared, from which the capacity of the reservoir at the time of survey is computed. The difference in capacity between two surveys indicates the loss of capacity due to sediment deposition during the intervening period.

2.4.3 Volumetric measurements in reservoirs are made by taking soundings and developing the configuration of the reservoir sides and bed below the water surface. Deposits above water level are measured by bank sections obtained by topographical survey method.

2.4.4 In case of small reservoirs sufficient soundings are taken below the water level either by a sounding pole or by lead line, so as to permit the drawings of contours to compute and compare capacity for any given elevation. In these reservoirs ranges may be spaced sufficiently close so that bottom contours may be drawn well. In some smaller reservoirs, the ranges may be dispensed with and independent sounding surveys made. Whenever desired bottom contours are developed for comparison of capabilities. For smaller reservoirs, reconnaissance method of surveying is also carried out. The reconnaissance survey has been designed to determine the approximate rate of loss of storage capacities, and consists in measuring the thickness of the deposited sediment from 15 to 20 or more well distributed locations in a reservoir by means of simple measuring device known as spud.

2.4.5 In case of large reservoirs, sounding by lead line or sounding pole or reconnaissance method cannot be applied as it would involve time and expenses. In such cases, volumes are found by sounding by means of supersonic. In such cases, volumes are found by sounding by means of supersonic sounding equipment along with silt ranges established usually at the time when the project is built. For large reservoirs this is the most feasible and practical method.

2.5 Rangeline Survey Method

Rangeline method of capacity survey consists of carrying out levelling or sounding along a fixed set of ranges. The object is to compute the areas at different cross sections and carry out volumetric computation on that basis. The range layout should be carefully planned and the reference monument should be connected with a triangulation network, supplemented by plane table or traverse survey, if necessary.

2.5.1 *Layout of Ranges*

2.5.1.1 Prior to impoundment of a reservoir it is necessary to have an accurate map on a relatively large scale for reservoir sites and upstream areas where sediment deposition may occur.

2.5.1.2 Before reservoir is filled proper location of silt ranges is made in sufficient number so that subsequent soundings on these ranges will furnish the necessary data for computation of silt volume. The ranges should first be located on a paper, in order to get a comprehensive idea as to how the ranges should lie with reference to each other and the reservoir as a whole. The point may need modification at site depending on topography etc. While fixing the ranges, the following points need careful consideration:

a) The silt ranges should be carefully located and the ranges should be monumented in the field so that the range monuments may be traceable after a period of about 3 to 5 years.
b) The location of the tributaries with its sediment characteristics is to be ascertained and this area may need close ranging.
c) Close spacing of ranges are preferable in the upper and shallower reaches than in the lower and deeper reaches.
d) If the reservoir is subject to heavy drawdown, the reaches between the drawdown level to the maximum water level should be more closely spaced, as the deposits and movement of silt throughout this range is greater than other parts of the reservoir.
e) Ground survey above the water level along these ranges is essential.
f) It is preferable if the ranges could be spaced parallel, but this need not be very rigid.
g) In all cases, however, reservoir width is very important.
h) The ranges may be spaced at 1 km intervals.
j) If the reservoir has embankment consequent on the tributaries joining the main river, this portion should be separately ranged and the ranges may have different orientation from the main ranges.
k) Range monuments may be fixed above the maximum water level.
m) Range monuments should not be located on the point of a short hill or abrupt change in reservoir section. At such places the elevation of the ground may show a variation within a relatively short distance away from the central line of the range so that the sounding which may vary a few metre off the central line may lead to erroneous results with regard to deposition.
n) If it is found not practicable to layout the ranges parallel to one another, a divergence of 10°

between the ranges may be permitted for the convenience of location, but not more than 30° may be permitted.

p) Range should cover the mouth of the tributaries joining the main river.

q) Sometimes the presence of bends or curves in the river makes it impracticable to rigidly adhere to the divergence limit set. In such cases, the stretch should be divided into short reaches where the limit of divergence are maintained in each reach. In the segments between the reaches, the reaches may have any divergence not greater than 90°. In these transition segments, the end ranges may be set very close to one another, or starting from a common point with a view to concentrate the irregularity into the smallest area so that it will have the least effect.

Where a tributary enters, or an arm of the lake is cut off, a new series of ranges may be started without any regard to the direction of the two main ranges of the segment. The first range should be across the mouth of the tributary and perpendicular to its general direction, or near to this as practical consideration would permit.

2.5.2 *Range Monuments*

2.5.2.1 The ends of the proposed ranges should be monumented in the field with a permanent type of monument. They may be of cement, concrete masonry, depending upon the availability of the material in the locality. These monuments should be adequately referenced so that they can be found several years later without much difficulty. Experience has shown that finding range monuments in the field, after vegetation has grown would be costly as well as time consuming. For properly referencing the range monuments, a net work of triangles should be established with reference to an accurate base line preferably taking the base line on the dam itself, where accurate linear measurement may be possible. Establishment of bench mark along the periphery of the reservoir at suitable intervals will also be necessary for establishing vertical controls whenever and wherever necessary. All triangulation stations, bench mark pillars, and range monuments should be properly indicated so that they may be identified easily. Some of the permanent objects in the shore should also be properly located so that they may be useful for horizontal control during the actual sounding work. The triangulation survey works may conform to the third degree of accuracy—Survey of India practice. All the range monuments may be properly numbered starting from the dam. Correct location of silt ranges on a contour map is necessary for obtaining the original capacity between the ranges.

2.5.3 *Base Line of Ranges*

2.5.3.1 After the range monuments have been located in the field, base profile, that is, cross section along the range is necessary for future comparison at appropriate intervals of resurveys. This may be done either by topographic survey before filling of the reservoir, or by means of echo-sounding immediately after filling. It is recommended that in reservoirs where the sides of the valley are steep and water depth is great, an accurate profile should be taken by surveying along the reach before filling of the reservoir. In reservoirs located in terrain where the topography is not steep, the depth of water is low and the width is great, the profile along the silt range could also be determined by sounding immediately after the reservoir is filled. Bank work, however, to supplement the sounding along the range above the water level will be necessary.

3. SEDIMENT SAMPLERS AND DENSITY MEASUREMENTS

3.1 Sediment bulk density can be measured by two methods namely, using a gamma density pole, or by removing a sample of known volume.

3.2 Density measurements and sediment samples are taken along range lines. The number of sample and measurement locations depends on the accuracy desired and the variability of the sediment. The entire depth of the sediment deposits needs to be sampled and its volume weight measured accurately for determining sediment accumulation. Consolidation continues to occur throughout the entire sediment depth.

4 COMPUTATIONAL PROCEDURE FOR CAPACITY SURVEY

4.0 The two basis approaches for computation of volume of deposit are based on: (i) Surface area/contour method, and (ii) Sectional area/range method.

4.1 Surface Area Approach

If the survey is done by the contour method, the contour map of the reservoir is prepared and by planimetering the successive areas enclosed by the contours, starting from the lowest contour a submergence area-elevation curve is first prepared. From this curve the area covered at different elevations can be obtained. The capacity may be worked out using the following methods:

a) Contour area interval method, and

b) Modified prisomoidal formula.

4.1.1 *Contour Area Interval Method*

The capacity between the successive unit elevations can be worked out arithmatically by taking the average submergence area and multiplying by the unit height.

4.1.2 *Modified Prismoidal Formula*

The capacity between the successive unit elevation can also be worked out by the modified prismoidal formula:

$$Vs = \frac{2H}{6}(A + 4B + C) - Vy$$

where

Vs = capacity between middle and top contours,

H = contour interval between A and B contour,

A = area of the bottom contour,

B = area of the middle contour,

C = area of the top contour, and

Vy = capacity between middle and bottom contours previously determined.

The capacity below the lowest contour may be computed by the contour area interval method which provides V_y. After finding the volume below the lowest contour this formula can be used progressively for each succeeding higher contour.

4.1.3 The cumulative value of the capacity between the successive unit elevations, obtained by any of the above two methods, starting from the lowest elevation, will give the new capacity of the reservoir at different elevations. The difference between the old capacity and the new capacity at any elevation will provide the accumulation of silt deposit between the surveys.

4.2 Sectional Area Approach

The basic requirement in this approach is the evaluation of cross sectional areas of different ranges in the reservoir. Based on the bed levels obtained on each range line, the cross-section of the reservoir for all range lines is generated. Then the cross sectional area at each range line for all required elevations up to FRL is worked out. The capacity at a particular elevation between two successive range line may be worked out using any of the following methods:

a) Average end area length method,
b) Prismoidal formula, and
c) Constant factor method.

4.2.1 *Average End Area Length Method*

The capacity between two successive range lines at any elevation up to FRL is worked out using the formula:

$$V = \frac{L}{2}(A_1 + A_2)$$

where

V = the capacity at elevation 'X' between two succesive range lines,
A_1, A_2 = area of successive cross-sections at elevation 'X', and
L = distance between the range lines.

4.2.2 *Prismoidal Formula*

The capacity between two successive ranges at any elevation may also be worked out using the prismoidal formula :

$$V = \frac{L}{3}(A_1 + A_2 + \sqrt{A_1 A_2})$$

where

V = the capacity between two successive range lines at elevation 'X',
L = distance between the range lines, and
A_1, A_2 = area of successive cross-sections at elevation 'X'.

4.2.3 *Constant Factor Method*

This method is a modification of the average and area length method. In this method the initial capacity of any given reach and its end areas are worked out based on the initial survey. The ratio of original capacity of the reach and its average end area at different elevations remain constant throughout the life of a reservoir and is known as "constant factor".

The new capacity between successive cross-sections at any elevation may be worked out using the following equation:

$$Vs = \frac{V_0}{A_0} \times An$$

where

$\frac{V_o}{A_o}$ = constant factor,
Vs = new capacity in the reach,
V_0 = original capacity in the reach,
A_0 = original average end areas of the reach, and
An = new average end areas of the reach.

4.2.4 The new capacity of the reservoir at any elevation may be worked out by summing up the capacities between the range line obtained from any of the three methods mentioned above. The difference between the old capacity and the new capacity at any elevation will provide the accumulation of silt deposit between the surveys.

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